Optimizing Frequency Channels in Cochlear Implants

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Questions

- **Will adults with cochlear implants benefit from a modified frequency allocation of their implant electrodes?**
- **Does increased resolution of formant information improve speech recognition in adults with cochlear implants?**
- **Do adults with CIs benefit from increased resolution of information about time varying formant structure across word boundaries?**

Background

- Cochlear Implants (CIs) are devices used by individuals with hearing loss to improve communication through the use of an electrode array that directly stimulates the auditory nerve.
- Average open-set speech recognition for CI users is well below that of normal-hearing adults.
- Most of the information about vowel identification is represented by spectral peaks (formants) below 2.5 kHz (1).
- Existing signal processing strategies utilize a logarithmic frequency-to-electrode allocation, mimicking the representation of frequencies along the basilar membrane in the cochlea (high frequencies at the base and low frequencies at the apex) (2), but this allocation may not optimally represent the formants that underlie vowel perception.
- This study examined a different frequency-to-electrode allocation which assigned more electrodes to lower frequencies, where essential information exists to support vowel identification.

Method

- **Participants (N = 12)**

Participant	Gender	Age (years)	Implantation Age (years)	Side of Implant	Hearing Aid	Etiology of Hearing Loss	Better Ear PTA (dB HL)
100001	F	62	54	B	N	Genetic	105
100002	F	64	62	R	Y	Genetic, progressive as adult	75
100003	M	64	61	L	N	Noise, Meniere's	80
100006	M	67	65	R	N	Genetic, progressive as adult	84
100007	M	56	52	B	N	Rubella, progressive	105
100008	F	54	48	R	Y	Genetic, progressive	105
100009	M	77	67	L	N	Genetic, progressive	93
100010	M	77	76	R	Y	Progressive as adult, noise, sudden	71
100016	F	61	59	R	N	Progressive as adult	105
100017	M	23	14	L	Y	Congenital, progressive	100
100019	F	73	67	L	N	Genetic, autoimmune	105
100025	M	57	56	R	Y	Autoimmune, sudden	76

Table 1. Cochlear implant participant demographics.
PTA = Unaided four-tone pure tone average at .5, 1, 2, and 4 kHz

Method (Continued)

- All were fit with a Cochlear Freedom processor using an ACE processing strategy.
- Out of the 22 electrodes, only electrodes 4, 8, 12, 16, and 20 were used.
- Two programs were developed and used for this study:
  - The **speech** program used 4 electrodes to represent vowel frequencies: 20 and 16 divided the F1 space in half, and 12 and 8 divided the F2 space in half.
  - The **standard** program, which had a logarithmic frequency allocation similar to a typical clinical map, used only 3 electrodes (20, 16, and 12) to represent the formant frequencies.

Electrode	Speech Program Frequency Allocation	Standard Program Frequency Allocation
20	250-550 Hz	250-722 Hz
16	550-936 Hz	722-1528 Hz
12	936-1528 Hz	1528-3066 Hz
8	1528-2440 Hz	3066-6000 Hz
4	2440-7938 Hz	6000-7938 Hz

Table 2. Frequency allocation for the **speech** program and the **standard** program

- **Tasks**
  - Participants were asked to listen to and repeat three types of stimuli:
    - Highly meaningful five-word sentences (3)
    - Words in isolation (4)
    - Non-meaningful but syntactically correct four-word sentences (5)
  - The stimuli were presented in three blocks, with one type of stimuli per block. Half of each block was heard while using the **speech** program, and half was heard while using the **standard** program, in a random order.
- **Analyses**
  - Responses were scored as percent words correct for the syntax-only and meaningful sentences.
  - For word lists, responses were scored as percent words, consonants, and vowels correct.
  - Arc sine transforms of data were used for statistical analyses.
  - Paired *t*-tests were performed to compare scores for individuals while using the **speech** and **standard** programs.
  - Linear regression analyses were performed to examine whether differences in any scores between the **speech** and **standard** programs predicted overall benefit to recognition of whole words or sentences.

Results

Participant	Meaningful SPEECH	Meaningful STANDARD	Words SPEECH	Words STANDARD	Vowels SPEECH	Vowels STANDARD	Syntax-only SPEECH	Syntax-only STANDARD
100001	99	94	48	48	72.2	66.7	60	52
100002	41	40	2.2	5.6	40	15.56	0	0
100003	75	28	13	6.7	47.8	56.7	0	0
100006	52	62	10	17	43.3	36.7	0	0
100007	79	77	16	17	27.8	20	28	22
100008	92	90	27	36	30	35.6	33	62
100009	86	65	17	20	25.56	23.3	27	16
100010	84	88	13	34	35.5	30	23	44
100016	15	8	0	3.3	48.9	35.6	24	4
100017	62	46	2.2	8.9	56.7	58.9	15	5
100019	90	88	27	33	14.4	14.4	33	31
100025	56	67	2.2	6.7	50	56.7	3	3
Mean Performance	69.23	62.8	14.73	19.63	41.01	37.51	20.5	19.92

Table 3. Individual participant scores for each task.

- The mean score was higher for the **speech** program than the **standard** program for both the meaningful sentences and vowels within words; however, our paired-samples *t*-test revealed that differences were not significant, and standard deviations were large.
- The only significant differences were that mean score for words and first consonant were greater for the **standard** program than the speech program, $t = 3.09$, $p = .01$, $t = 2.44$, $p = .03$, respectively.
- Linear regressions showed that improvements in vowel scores strongly predicted improvements in meaningful sentence scores, $\beta = .84$, $F = 23.38$, $p = .001$, and improvements in syntax-only sentence scores, $\beta = .67$, $F = 7.85$, $p = .026$.

Conclusions

- There was a substantial amount of variability in program performance for adults with CIs.
- Approximately one-third of the participants benefited from the **speech** program over the **standard** program.
- Improved representation of vowel information benefited adults with CIs when listening to meaningful and nonsense sentences, suggesting that improved access to formant information might support better recognition of the time varying formant structure of running speech.
- These results suggest that CI users might benefit from having more electrodes allocated to the lower formant frequencies, but more research needs to be done on this topic before it is used clinically.
- Although we can specify the frequencies in the electrodes, there is no way of knowing how frequency was represented along the basilar membrane or auditory nerve. Future goals include developing a method to determine representation as a first step, so that vowel formant frequencies can be allocated meaningfully.

References

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